1.1. Interaction of photons with matter.

1.1.1. Gamma rays and x-rays.

The gamma and x-rays are both forms of electromagnetic radiation individual wave packets of this radiation are called photons. The main difference between gamma ray and x-rays is their origin. While x-rays are produced by atomic excitation or from an electron as it changes direction when passing an atomic nucleus; this latter type of x-ray is called bermstrahlung, gamma rays are emitted by transition from excited states in the nucleus [1].

1.1.2. Photons interaction.

When a narrow beam of monoenergetic photons with incident intensity I_o entering a layer of material the number of photon that interacts with it I^* is given by (Eq.1.1).

$$I^* = I_0\left(1 - e^{-\mu x}\right) \tag{1.1}$$

Where μ is the summation of all the probabilities of one photon interacting with the matter per unit distance. μ depends on photon energy and type of matter which will be discussed later. x is the distance of matter inside which the photon travels. Gamma rays do not carry an electric charge and therefore may pass through a large number of atoms without any interaction taking place. However in energy range E_γ from a few keV up to some MeV they can be interact with an atomic electron or an atomic nucleus in one of number of ways [2]. The most important of these are:

1.1.2.1. Rayleigh scattering.

It's also called coherent, Thomson, classical, elastic scattering and (non-ionizing) is shown in (Fig.1.1) where the incident photon interacts

with the outer most electrons and the photons is scattered without any excitation or ionization to the atom. This scattering is effective with energy less than 0.1 MeV and σ_{coh} depends on the photon energy and the atomic number of the matter. At high energies and small atomic number this effect is neglected.

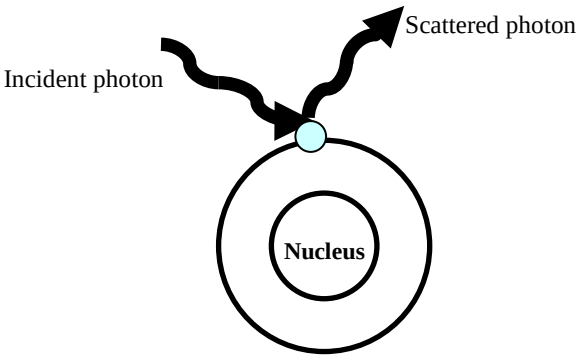

Figure 1.1: Coherent Scattering (non-ionizing) [3].

Where: σ_{coh} cross section of the Rayleigh scattering.

1.1.2.2. Photoelectric absorption.

The process of photoelectric absorption is shown in (Fig.1.2) an incident photon Eγ below 0.5 MeV is completely absorbed by an atom in the absorber material, and one of the atomic electrons is ejected. This ejected electron is known as a photoelectron.

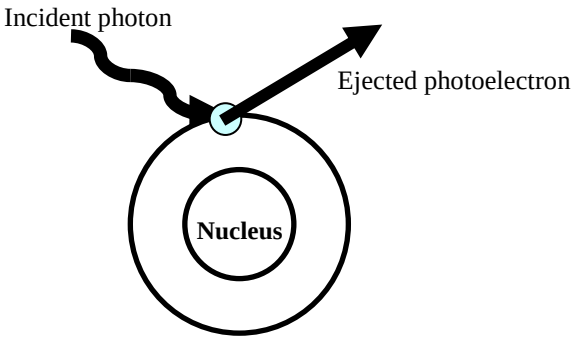

Figure 1.2: Photoelectric absorption [3].

the electron must be bound to the atom, to conserve energy and momentum. The kinetic energy of the photoelectron E_e is given by (Eq.1.2).

$$E_e = E_\gamma - E_b \quad (1.2)$$

Where E_b is the binding energy of the atomic electron. The vacancy left in the atomic structure by the ejected electron is filled by one of the electrons (Auger electron) from a higher shell. This transition is accompanied by an emission of an x- ray.

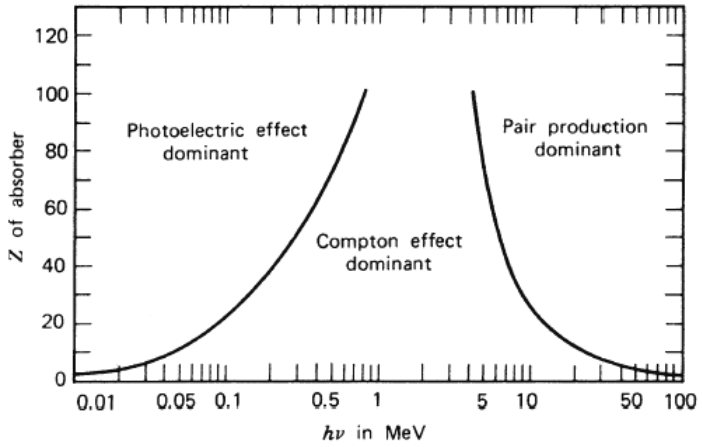

Figure 1.3: The relative importance of the three major types of γ-ray interaction .the lines show the value of Z and hν for which the two neighboring effects are just equal [2].

The probability of the photoelectric effect per atom can be described in (Fig.1.3) and by the following relationship (Eq.1.3).

$$\sigma_{pe} = const \frac{z^n}{E_\gamma^{3.5}} \quad (1.3)$$

Where: σ_{pe} cross section of the photon effect.

z atomic number of interacts martial.

n varying exponent between 4 and 5.

E_γ quantum of the x-ray energy (photon energy).

1.1.2.3. Compton scattering.

Compton or incoherent scattering process occurs in energy rangy 0.5 to 3.5 MeV (Fig.1.4) only a portion of the photon energy is transferred to a "Compton electron "and the remainder is carried away by a secondary photon . The energies of the outgoing electron and secondary photon are related to the scattering angel θ after scattering, the secondary photon can

be absorbed by photoelectric absorption or scattered again by the Compton scattering process .it is possible that the photon or electron scatters out of the medium without depositing its full energy.

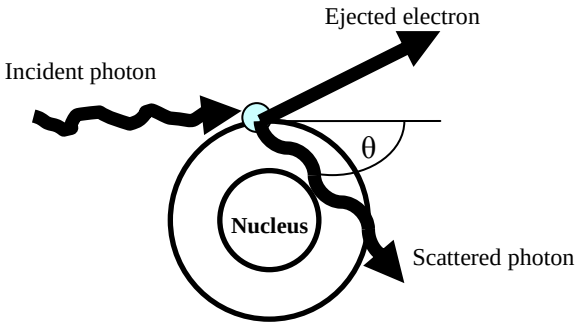

Figure 1.4: Compton Scattering [3].

From the conservation of the energy and momentum leads us to the following expression (Eq.1.4) for the energy of the scattered photon:

$$E_{\gamma}^{*} = \frac{E_{\gamma}}{1+\left(E_{\gamma} \big/ m_0 c^2\right)(1-\cos\theta)} \tag{1.4}$$

Where E_γ is the incident photon energy, E_γ^* is the energy of the scattered photon, θ is the scattering angel and $m_o c^2$ the electron rest mass energy. The kinetic energy of the electron after the collision is given by (Eq.1.5).

$$E_{\gamma}^{`} = E_{\gamma} - E_{\gamma}^{*} = \frac{E_{\gamma}^{2}(1-\cos\theta)}{m_o c^2 + E_{\gamma}(1-\cos\theta)} \tag{1.5}$$

It can be seen that, since all scattering angles are possible, the electron energy ranges from zero for $\theta=\theta^o$ to $2E_\gamma^2 \Big/ \left(m_0 c^2 + 2E_\gamma\right)$ for $\theta=180^o$ and that the photon never loses the whole of its energy in any one collision. The probability of the Compton Effect per atom can be described in (Fig.1.3) and by the following relationship (Eq.1.6).

$$\sigma_{incoh} = const\,\frac{z}{E_\gamma} \tag{1.6}$$

Where: σ_{incoh} cross section of the photon effect.

E_γ quantum of the x-ray energy (photon energy).

z atomic number of interacts material.

1.1.2.4. Pair and triple productions.

The pair production mechanism only occurs for photon energies equal 1 or above 1.022 MeV as shown in (Fig.1.5.1).

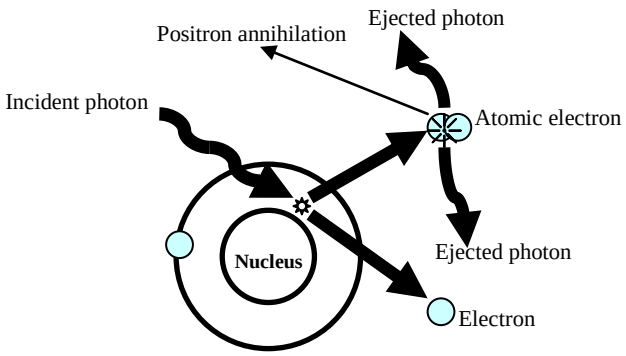

Figure 1.5.1: pair production [3].

Here photons are converted to electron pairs under the effect of the filed of a nucleus. Since one electron and one positron are formed, the photon must have energies equivalent to at least two electronic masses (2x0.511 MeV) and the excess photon energy is shared between the created electron and positron pair. The annihilation of the positron with atomic electrons produces two photons in opposite directions, each with 0.511 MeV. The total cross-section for this process increases with energy above the threshold energy. The probability of the pair production effect per atom can be described in (Fig.1.3) and by the following relationship (Eq.1.7).

$$\sigma_{pair} = const\ z^2 \ln\left(E_\gamma - 2m_0c^2\right) \qquad (1.7)$$

Where: σ_{pair} cross section of the photon effect.

E_γ quantum of the x-ray energy (photon energy).

z atomic number of interacts material.

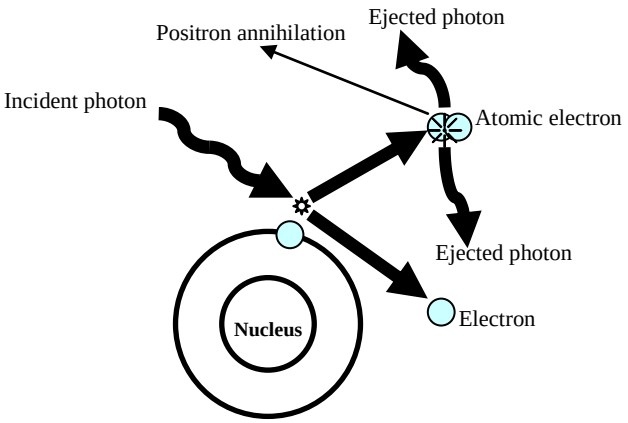

Figure 1.5.2: triple production [3].

If pair production takes place in the field of an atomic electron the threshold energy is equal to 2.044 MeV. it called the triple production (Fig1.5.2) interacting atomic electron itself gets part of residual photon energy in the form of kinetic energy .the probability of the triple production effect σ_{triple} is far less than the probability of the pair production effect σ_{pair} by about two decades .

1.2. Gamma-ray attenuation.

1.2.1. Attenuation coefficients.

The reduction of intensity I of photon flux is called attenuation when monoenergitic gamma rays are collimated into a narrow beam and after passing through an absorber of variable thickens, the result should be simple exponential attenuation of the gamma rays as also shown in (Fig.1.7) by absorption or by scattering can be characterized a fixed probability of occurrence per unit path length in the absorber . The sum of these probabilities is simply the probability per unit path length that the gamma-ray is removed from the beam given by (Eq.1.8).

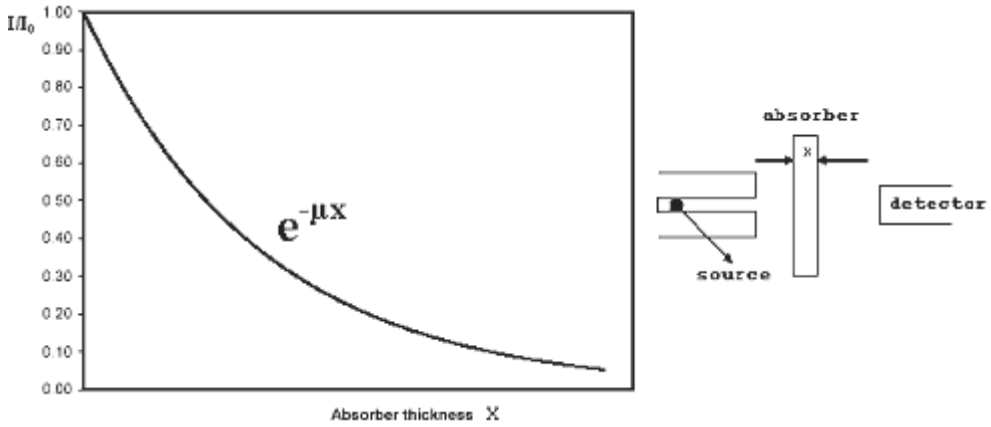

Figure 1.7: Intensity variation of the gamma rays passing through a material [4].

$$\mu=\sigma_{coh}+\sigma_{pe}+\sigma_{incoh}+\sigma_{pair}+\sigma_{triple} \quad (1.8)$$

Where μ called the linear attenuation coefficient (cm^{-1}). The number of transmitted photons I is given by (Eq.1.9).

$$I = I_0 e^{-\mu x} \quad (1.9)$$

The linear attenuation coefficient μ plotted as function of radiation energy can be describe as in (Fig.1.8).

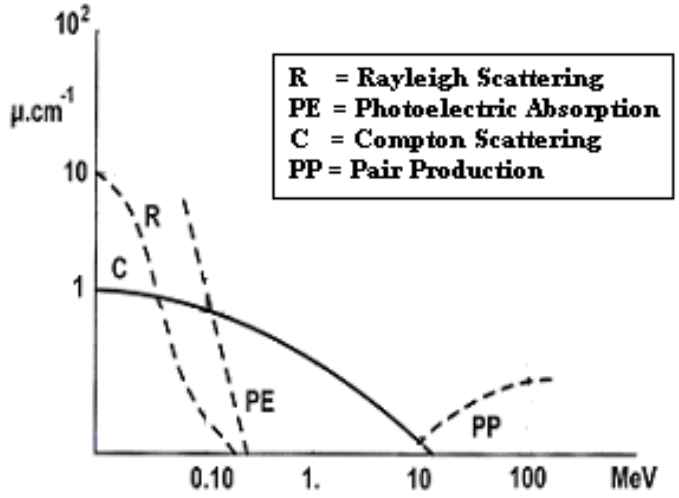

Figure 1.8: The linear attenuation coefficient μ plotted as function of radiation energy [5].

The gamma-ray photons can also be characterized by their mean free path λ, defined as the average distance traveled in the absorber before an interaction takes place. Its value can be obtained from (Eq.1.10).

$$\frac{1}{\mu} = \lambda = \frac{\int_0^\infty x\, e^{-\mu x} dx}{\int_0^\infty e^{-\mu x} dx} \qquad (1.10)$$

And is simply the reciprocal of the linear attenuation coefficient. Typical values of λ range from few mm to tens of cm in solids for common gamma-ray energies. Use of the linear attenuation coefficient is limited by the fact that it varies with the density of the absorber, even though the absorber material is the same. Therefore, the mass attenuation coefficient for HPGE (Fig.1.9) is much more widely used and is defined as (Eq.1.11).

Mass attenuation coefficient = (μ/ρ) (cm^2/gm) (1.11)

Where ρ represents the density of the medium. For a given gamma-ray energy, the mass attenuation coefficient does not change with the physical state of a given absorber. For example, it is the same for water whether present in liquid or vapor form. The mass attenuation coefficient of a compound or mixture of elements can be calculated from (Eq.1.12).

$$\left(\frac{\mu}{\rho}\right)_c = \sum_i w_i \left(\frac{\mu}{\rho}\right)_i \qquad (1.12)$$

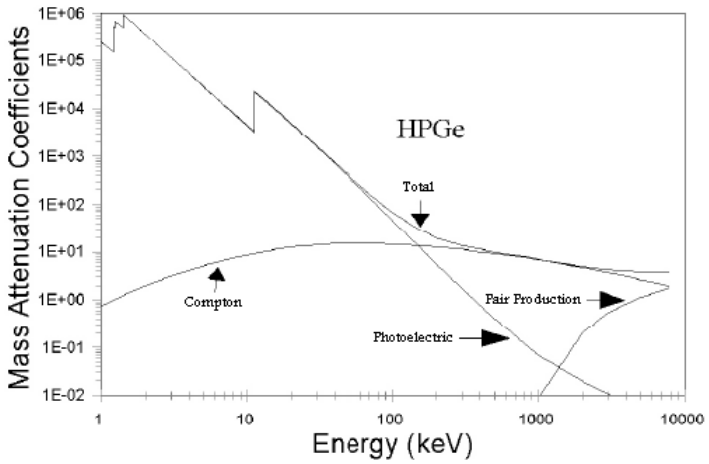

Figure 1.9: The mass attenuation coefficient μ plotted as function of radiation energy for (HPGe) [6].

Where the w_i factors represent the weight fraction of element i in the compound or mixture [4].

1.2.2. Absorber mass thickness.

In term of the mass attenuation coefficient, the attenuation law for gamma ray now takes the form (Eq.1.13).

$$I = I_0 e^{-\left(\mu/\rho\right)\rho x} \tag{1.13}$$

The product ρx known as the mass thickness of the absorber .the units of mass thickness is (gm/cm^2) [4].

1.3. Gamma ray application.

In radiation physics, measuring and studying the energy gamma spectra emitted from radioisotopes are very important and have many applications [7].

1.3.1. Study of the nuclear structure.

The study of the emitted γ-ray from radioactive sources is one of the primary means to learn about the structure of excited nucleus states. γ-ray detection is relatively easy to accomplish and can be done at high

resolution and with high precision. Knowledge of the locations and properties of the nuclear excited states is essential for the evaluation of calculations based on any nuclear model. Thus γ-ray spectroscopy is the most direct, precise and often the easiest way to obtain that information.

1.3.2. Identification of the radioactive isotope.

Each radioactive isotope has a number of allowed transitions inside the nucleus between the different levels of energy with certain probability .these transitions are accompanied by emission of γ-rays photons with energies equal to the different between the initial and final levels. So an isotope may emit γ-rays with different energies but the ratio among the intensities of this energy peak (photon energies) is constant and depends on the probabilities of transitions inside the isotope. From the energy peaks and the ratio among their intensities the isotope can be identified, where each radioactive isotope has a certain spectrum (energy peaks and intensities). From the intensity, if the detector's efficiency is exactly known, the isotope activity and its concentration in a sample can determine.

1.3.3. Measuring the absorbed doses.

γ-ray has harmful effects on the human body; if the body is exposed to high active sources for a long times γ-ray is also used in medicine for treatment the cancer .so that there are upper limits for the exposure, that the human must not cross them through certain interval of time to get round bad effects .γ-ray effects depend on the amount of radiation that is absorbed in the body that is called the absorbed does.

1.3.4. Determination of the interaction cross sections.

γ-rays play an important part of the conservation of energy in the nuclear interaction. So many nuclear interactions, products are

accompanied by γ-rays with certain finite energy. From the intensity of γ-ray energy, the probability of the interaction to take place with respect to the original flux can be determined. Interactions take place by many ways with different products .to determine the probability of each interaction, γ-ray energy and intensity for each type are followed and measured, where each interaction has a certain γ-ray spectrum. From γ-ray spectrum and the original flux the cross section for each group of products is determined. This brief survey clears that, γ-ray spectrum has important applications and γ-ray spectrum with high accuracy is required. To get a spectrum with high accuracy, one should have detection and recording system, plus good values for detectors factors that concern the measurement analysis.

1.4. The measurement method.

The basic idea of measuring any radiation is the interaction of radiation with the detector matter .the radiation gives part or all of its energy to the detector through the interaction .and the recording of the event takes place according to the detection system and the deposited energy from the interaction .i.e. the measurements include the interactions of photons with the detector matter, the detection system and the deposited energy in the detector [2].

1.4.1. The detection system.

The detection systems are classified into two types according to the method of operation either pulse-type system. Where the output consists of voltage pulse, one pulse per detected particle. or current-type system, where the output is an average value resulting from detection of many particles .to study the energy distribution , pulse-type systems are used .a basic pulse-type system consists of instrument shown in (Fig.1.11) ,the component and their function are as follows :

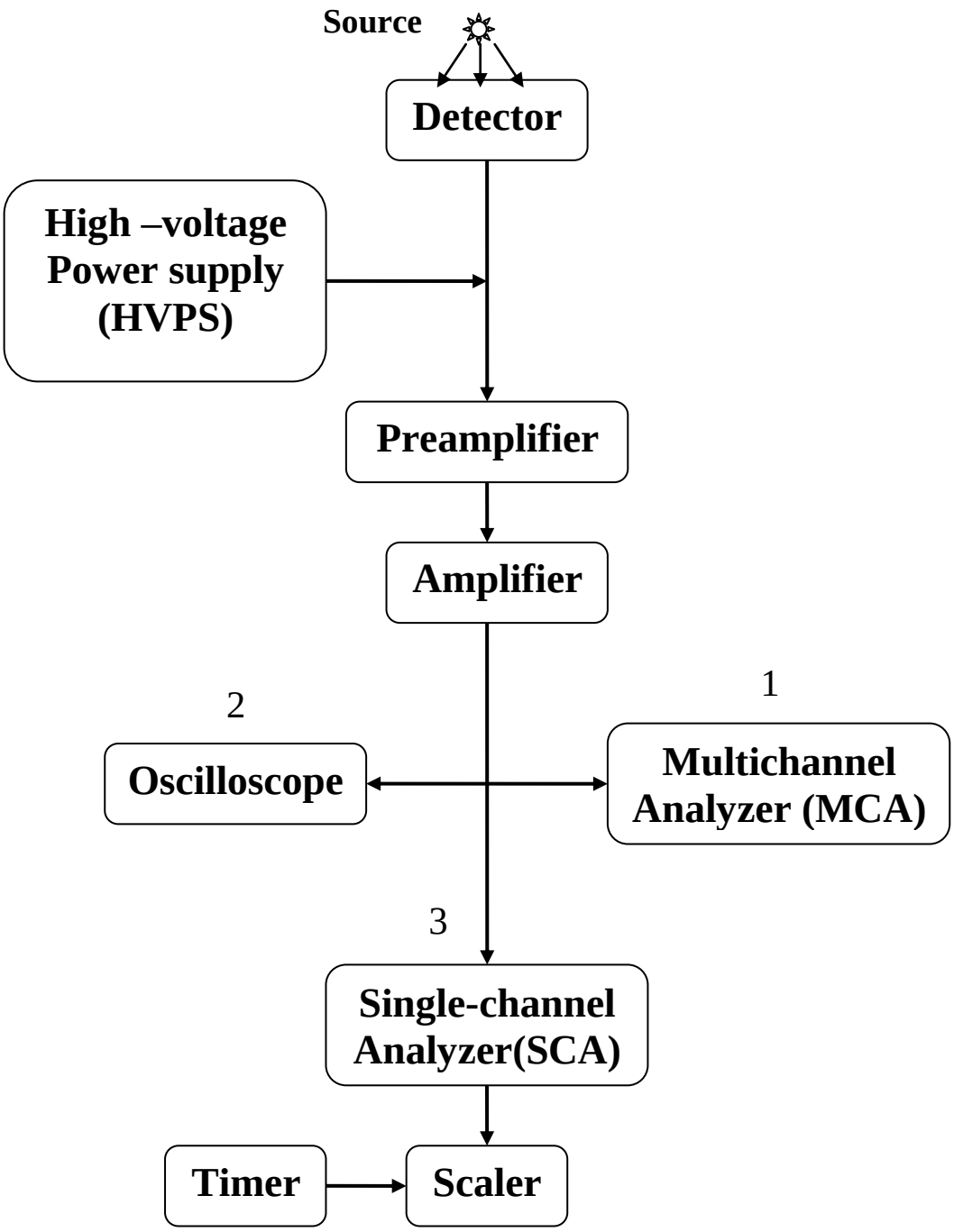

Figure 1.11: Schematic diagram of a typical gamma detector [2].

1.4.1.1. The detector.

The function of the detector is to produce a voltage signal related to the incident photon .there are several types of pulse-type detector, such as scintillation and semiconductor detectors which will be discussion later in this chapter.

1.4.1.2. The high-voltage power supply.

The high-voltage power supply (HVPS) provides a positive or negative voltage necessary for the operation of the detector. Most detectors need positive high voltage (HV).

1.4.1.3. The preamplifier.

The primary purpose of preamplifier is to provide an optimized coupling between the output of the detector and the rest of the detection system .the preamplifier is also necessary to minimize any source of noise that may change the signal.

1.4.1.4. The amplifier.

The main function is amplifying the pulse delivered from the preamplifier many timed and make it a stable form to be counted.

1.4.1.5. The multichannel analyzer (MCA).

The detectors convert the photon energy that is deposited from the interaction in the detector, into pulse with certain height that can be recorded. The device, that records the pulse, is called multichannel analyzer (MCA). This device is divided into windows (channel) each window has a width of voltage between certain limits of voltage V and $V+\Delta V$.V is the lower limit of voltage,ΔV is the voltage width and $V+\Delta V$ is the upper limit of voltage that corresponds to a certain pulse height that is recorded in it . The distribution of pulses in the channels is an image of

the distribution of the energies of the photons that are deposited in the detector.

1.4.1.6. The oscilloscope.

The oscilloscope is an instrument that permits the study of rapidly changing phenomena, such as sinusoidal voltage or the pulse of a counter. The phenomenon is observed on a fluorescent screen. The horizontal axis of the screen measures time. The vertical axis gives volts.

1.4.1.7. The signal-channel analyzer (SCA).

The SCA is used to eliminate the electronic noise and, in general, to reject unwanted pulses. When a pulse is amplified, the electronic noise that is always present in a circuit is also amplified. If one attempts to count all the pulses present, the counting rate may be exceedingly high. But electronic noise is nuisance and it should not be counted. The unite count only pulses above a certain height.

1.4.1.8. The scaler.

The scaler is a recorder of pulses. For every pulse entering the scaler, a count of one is added to the previous total. At the end of the counting period, the total number of pulses recorded is displayed.

1.4.1.9. The timer.

The timer is connected to the scaler, and its purpose is to start and stop the scaler at desired counting time intervals.

1.4.2. Energy deposition in detector.

1.4.2.1. The detector response function.

Photons are detected by means of the electrons they produce when they interact in the material of which the detector is made. The main interactions are photoelectric effect, Compton scattering, and pair

production. The electrons (or positrons) produced by these interactions deposit their energy in the counter (which knows as response function). And thus generates a voltage pulse that signifies the passage of the photon. The height of the voltage pulse is proportional to the energy deposited in the detector [2].

1.4.2.2. The deposited energy by photons.

If there is monoenergetic source, how are the photons from this source recorded by the detection system? In other words, what is its image in the (MCA) recording system? As mentioned before, the height of the recording pulse is proportional to the photon deposited energy and thus is stored in certain channel .so to answer the question, the method of energy deposition must be studied. Each interaction is followed individually and all its probabilities are mentioned. First, Rayleigh scattering doesn't deposit any measurable energy, so its recording probability is vanishing. In the photoelectric interaction, the photon gives all its energy to an inner electron and disappeared .the range of electrons in scintillation or semiconductor detector is very short that it can be assumed that all the electron energy will be deposited promptly in the detector. i e., there is a probability for the photon to be totally recorded from the photoelectric interaction . In Compton scattering, only a fraction of the photon energy is given to an electron. The energy of the electron is deposited in the detector. i.e., there is a probability of the photon is recorded from Compton scattering. In the pair and triple production, the kinetic energy of each particle is deposited in the detector i.e., there is probability of the photon is recorded from the pair and triple production [2].

1.4.2.3. Modes of energy deposition in the detector.

1.4.2.3.1. Energy deposition by photons with E_γ<1.022 MeV.

A photon with E_γ<1.022 MeV can interact only through the photoelectric or the Compton Effect. If a photoelectric interaction takes place, the photon disappears and an electron appears with energy equal to E_γ-E_b, where E_b is the binding energy of that electron. The range of electrons in a solid, either a scintillator crystal or a semiconductor is so short that it can be safely assumed that all the electron energy will be deposited in the detector (Fig.1.12), if the interaction occurs very close to the wall, the electron may deposit only part of its energy in the counter (Fig.1.12), but the probability of this happening is small. In practice, one assumes that all the photoelectrons deposit all their energy in the detector. This energy is less than energy of the incident photon by the amount E_b. If Compton scattering takes place, only a fraction of the photon energy is given to an electron. A scattered photon

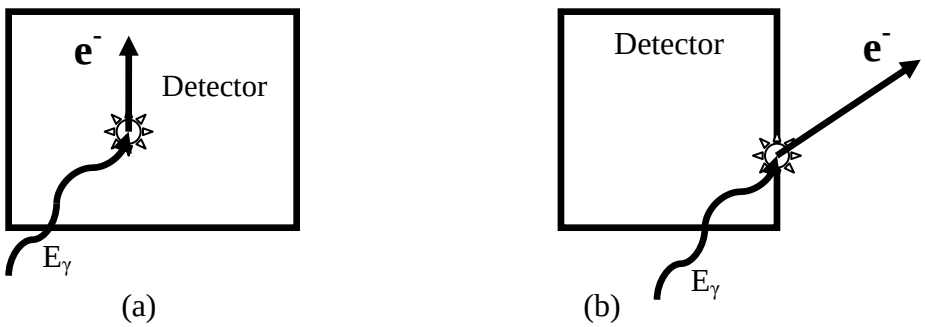

Figure 1.12: as a result of a photoelectric interaction the photon disappears. In (a), all the energy often electron is deposited in the detector. In (b), part of the energy is deposited in the wall [2].

Still exists carrying the rest of the energy. The energy of the electron is deposited in the detector. And the scattered photon may or may not interact again inside the detector. The probability of second interaction depends on the size of the counter (Fig.1.13), on the position of the first

interaction, on the energy of the scattered photon, and on the material of which the detector is made. unless the detector in infinite in size , there is always a chance that the scattered photon may escape , in which case a pulse will be formed with height proportional to an energy which is less than energy of the incident photon .

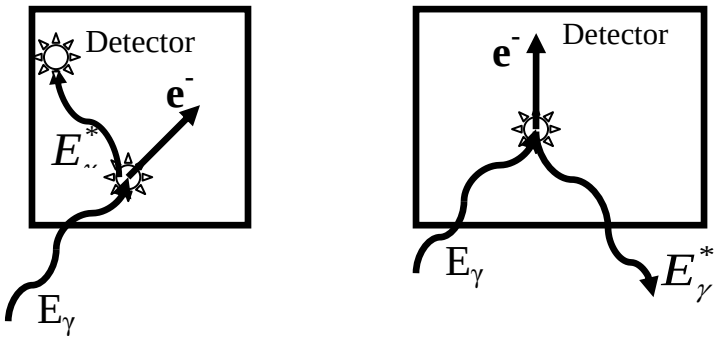

Figure 1.13: The scattered photon may or may not interact again inside the detector [2].

The monoenergetic source produces in a MCA the measured spectrum of some photons produce pulses that register in channel C_o, corresponding to the source energy E_o and thus contribute to the main peak of the spectrum, which is called the full-energy peak. The Compton electrons are responsible for the continuous part of the spectrum extending from zero channels up to CC channel

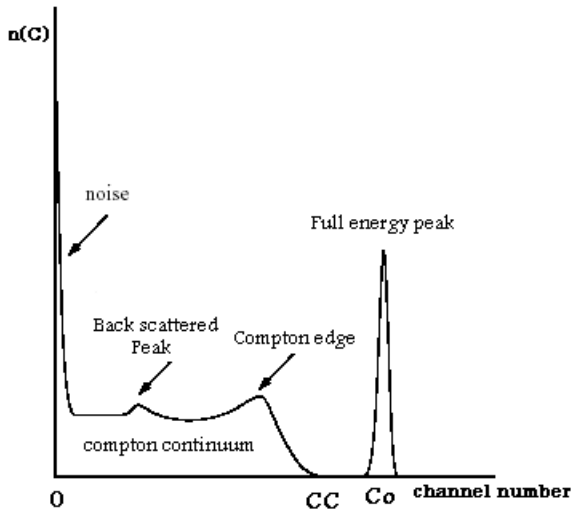

Figure 1.14: The spectrum energy distribution for photons with E_γ<1.022 MeV [8]

and called the Compton continuum. The end of the Compton continuum, called the Compton edge, since no detector exists with perfect energy resolution, the measured spectrum looks like that of (Fig.1.14), Sometimes the Compton interaction occurs very close to the surface of the detector or in the material of the protective cover surrounding the detector(Fig.1.15).

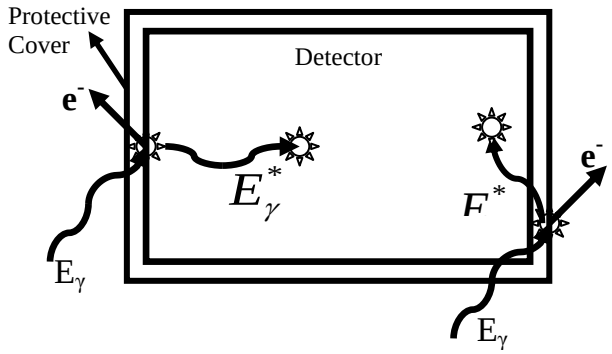

Figure 1.15: If Compton scattering occurs close to the surface of the detector, the only energy deposited may be that of the scattered photon [2].

Then there is a high probability that the electron escapes and only the energy of the scattered photon is deposited in the detector. Occasionally a rather broad peak is observed in γ-ray spectra. This peak is called the backscatter peak due to interaction scattered photon from Compton scattered [2].

1.4.2.3.2. Energy deposition by photons with E_γ>1.022 MeV.

If E_γ>1.022 MeV, pair and triple productions are possible in addition to photoelectric effect and Compton scattering. As result of pair production, the photon disappear and an electron-positron pair appears, at the expense of 1.022 MeV transformed into the pair's rest mass, the total kinetic energy of the electron-positron pair is (E_γ-1.022) MeV this energy is deposited in the detector the positron slows down until combines with an atomic electron, the two annihilate. And two gammas are emitted, each

with energy 0.511 MeV there is several possibilities for the fate of this annihilation gammas [2].

1- the energy of both annihilation gammas is deposited in the detector ,then, a pulse height is proportional to energy E_γ MeV (full energy peak).
2- Both annihilation photons escape, a pulse height is proportional to energy (E_γ-1.022) MeV (the double-escape peak).
3- One annihilation photons escape, a pulse height is proportional to energy (E_γ-0.511) MeV (the single-escape peak).

So if a source emits only one gamma, the measured spectrum will certainly show:

1- The full energy peak.
2- The Compton edge.

Other peaks that may be observed are:

3- Backscatter peak.
4- The single-escape peak.
5- The double-escape peak.

1.5. Energy spectrum for various detector sizes.

1.5.1. Small detectors.

We first examine the expected response of detectors whose size is small compared with the mean free path of the secondary gamma radiations produced in interactions of the original gamma rays. These secondary radiations consist of Compton scattered gamma rays, together with annihilation photons formed at the end of the tracks of positrons created in pair production. Because the mean free path of the secondary gamma rays is typically of the order of several centimeters, the condition of "small-ness" is met if the detector dimensions do not exceed 1 or 2 cm. At the same time, we retain our original simplifying assumption that all

charged particle (photoelectron, Compton electron, pair electron, and positron) is completely absorbed within the detector volume.

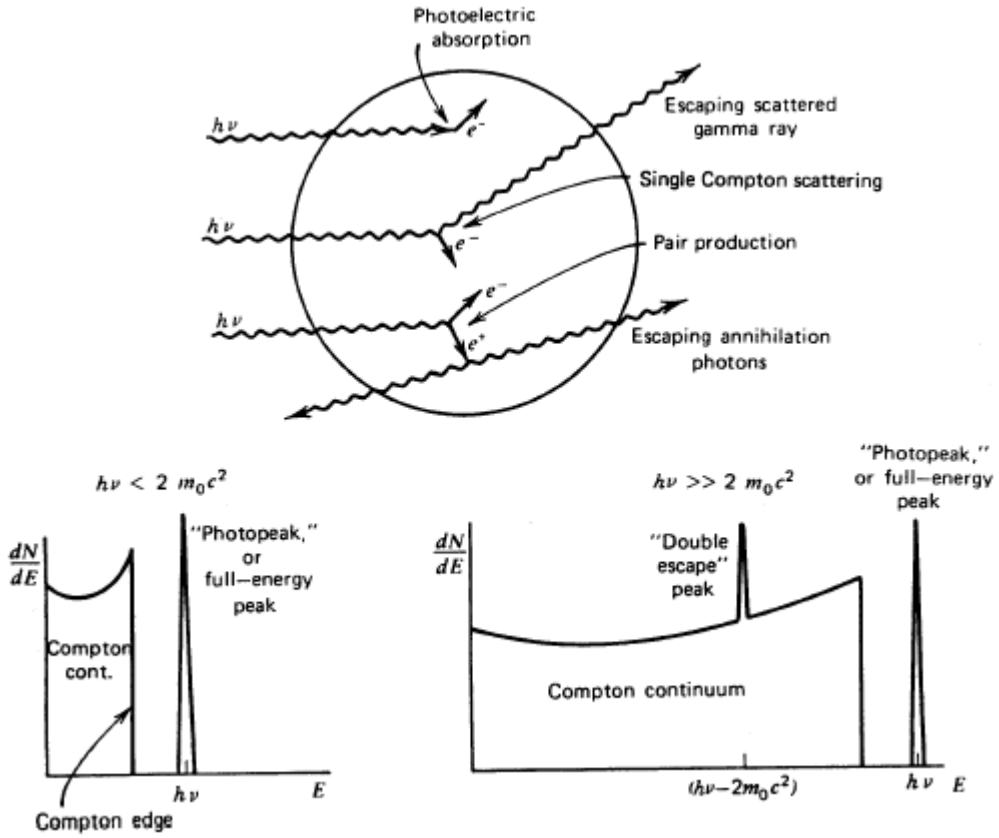

Figure 1.16: "The small detector ". The processes of photoelectric absorption and single Compton Scattering gives rise to the low energy spectrum at the left. At higher energies .the pair Production adds a double escape peak shown in the spectrum at the right [9].

The predicted electron energy deposition spectra under these conditions are illustrated in (Fig1.16). If the incident gamma-ray energy is below the value at which pair production is significant, the spectrum only from the combined effect of Compton scattering and photoelectric absorption. The continuum of energies corresponding to Compton scattered electrons is called the Compton continuum, whereas the narrow peak corresponding to photoelectrons is designated as the photopeak. For the "small" detector, only single interactions take place, and the ratio of the area under the photopeak to the area under the Compton continuum is the same as the ratio of the photoelectric cross section to the Compton cross section in the detector material.

If incident gamma-ray energy is sufficiently high (several MeV), the results of pair production are also evident in the electron energy spectrum. for a small detector , only the electron and positron kinetic energies are deposited , and the annihilation radiation escapes .The net effect is to add a double escape peak to the spectrum located at an energy of $2m_0c^2$(~1.02 MeV) below the photopeak. The term double escape refers to the fact that both annihilation photons escape from the detector without further interaction [2].

1.5.2. Very large detectors.

As an opposite extreme case, imagine that gamma rays could be introduced near the center of a very large detector, perhaps in an arrangement resembling that of (Fig.1.17). The detectors dimensions are now assumed to be sufficiently large so that all secondary radiations, including Compton scattered gamma rays and annihilation photons, also interact within the detector active volume and none escape from the surface. For typical gamma-ray energies, this condition would translate into requiring detector dimensions on the order of many tens of centimeters, unrealistically large for most practical cases.

Nonetheless, it is helpful to see how increasing the detector size greatly simplifies its response function. Some typical histories, obtained by following a particular source gamma ray and all subsequent secondary radiation, are sketched in (Fig.1.17). If the initial interaction is a Compton scattering event, the scattered gamma ray will subsequently interact at some other location within the detector. This second interaction may also be a Compton scattering event; in which case a scattered photon of still lower energy is produced. Eventually, a photoelectric absorption will occur and the history is terminated at that point.

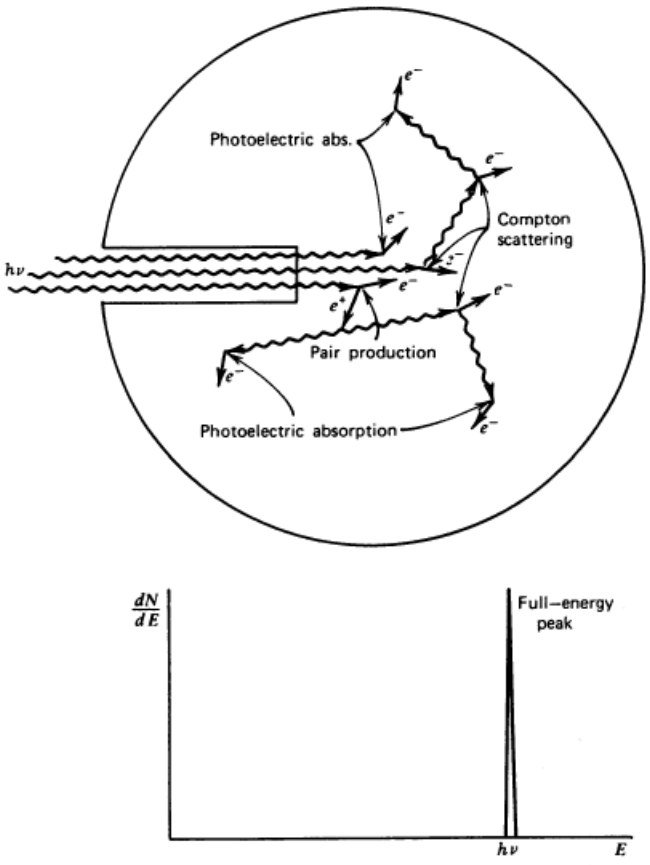

Figure 1.17: "the large detector". All gamma ray photons deposited all their energy in the detector. Some representative histories are shown in the top [9].

It is important to appreciate the small amount of time required for the entire history to take place. The primary and secondary gamma rays travel at the speed of light. If the average migration distance of the secondary gamma rays is of the order of 10 cm, the total elapsed time from start to finish of the history will be less than a nanosecond. This time is substantially less than the inherent response time of virtually all practical detectors used in gamma-ray spectroscopy. Therefore, the net effect is to create the Compton electrons at each scattering point and the final photoelectron in time coincidence. The pulse produced by the detector will therefore by the sum of the responses due to each individual electron. If the detector responds linearly to electron energy, then a pulse is produced which is proportional to the total energy of all the electrons produced along the history. Because nothing escapes from the detector,

this total electron energy must simply be the original energy of the gamma-ray photon.

The same type of argument can be used if the history involves a pair production event .The annihilation photons formed when the positron is stopped are now assumed to interact through Compton scattering or photoelectric absorption elsewhere in the detector . Again, if the detector is large enough to prevent any secondary radiation from escaping. The sum of the kinetic energies of the electron-positron pair and subsequent Compton and photoelectrons produced by interaction of the annihilation radiation must equal the original gamma-ray photon energy. Therefore, the detector response is again simply proportional to the original gamma-ray energy.

The detector response function now consists of the single peak shown in (Fig.1.17) rather than the more complex function shown in (Fig.1.16). The ability to interpret complex gamma-ray spectra involving many different energies is obviously enhanced when the response function consists of a single peak.

The corresponding peak in the response function is often called the photopeak. Just as in the case of the small detector. It should be realized, however, that in addition to simple photoelectric events, much more complex histories involving multiple Compton scattering or pair production also contribute pulses that fall within this peak. A better name is the full-energy peak because it represents all histories in which all of the original gamma-ray energy is fully converted to electron kinetic energy [2].

1.5.3. Intermediate size detectors.

The spectrum for low to medium gamma-ray energies (where pair production is not significant) again consists of a Compton continuum and

photopeak. Now, however, the ratio of the area under the photopeak to that under the Compton continuum is significantly enhanced over that for the very small detector due to the added contribution of multiple events to the photopeak. At very low energies (say, <100 keV) the Compton continuum may effectively disappear.

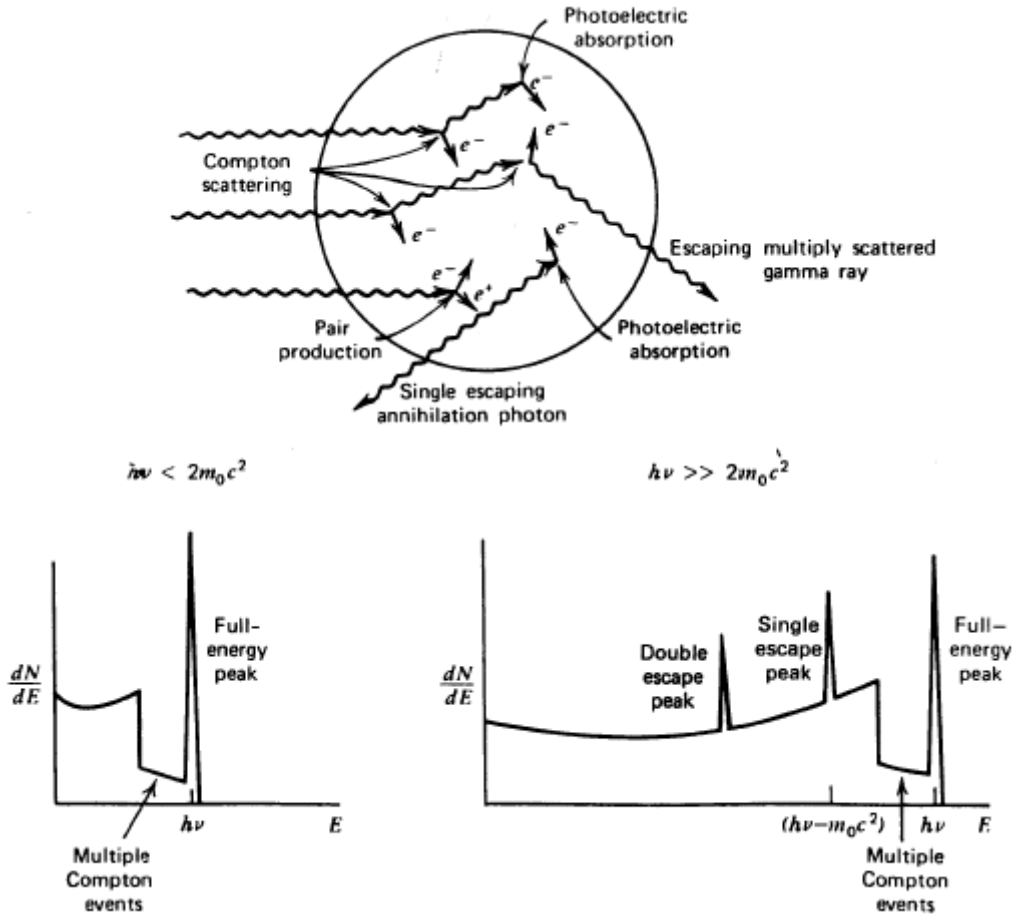

Figure 1.18: "Intermediate size detectors". In addition to the continuum from single Compton scattering and the full energy peak, the spectrum at the left shows the influence of multiple Compton events followed by photon escape. The full energy peak also contain some histories that began with Compton scattering .at the right, the single escape peak corresponds to initial pair production interactions in which only one annihilation photons leaves the detector without further interaction. a double escape peak will also be present due to those pair production events in which both annihilation photons escape [9].

At medium energies, the possibility of multiple Compton scattering followed by escape of the final scattered photon can lead to a total energy deposition that is greater than the maximum predicted for single scattering. These multiple events can thus partially fill in the gap between

the Compton edge and the photopeak, as well as distort the shape of the continuum predicted for single scattering.

If the gamma-ray energy is high enough to make pair production significant, a more complicated situation prevails. The annihilation photons now may either escape or under go further interaction within the detector. These additional interactions may lead to either partial or full energy absorption of either one or both of the annihilation photons. If both annihilation photons escape without interaction, events occur that contribute to the double escape peak discussed previously. Another relatively frequent occurrence is a history in which one annihilation photon escapes but the other is totally absorbed. These events contribute to a single escape peak, which now appears in the spectrum at an energy of m_0c^2 (0.511 MeV) below the photopeak. A continuous range of other possibilities exists in which one or both of the annihilation photons are partially converted to electron energy through Compton scattering and subsequent escape of the scattered photon. Such events accumulate in a broad continuum in the pulse height spectrum lying between the double escape peak and the photopeak [2].

1.5.4. Effects of surrounding materials.

In any practical application, a detector used for gamma-ray spectroscopy is surrounded by other materials that can have a measurable influence on its response.

All these materials are potential sources of secondary radiations that can be produced by interactions of the primary gamma rays emitted by the source. If the secondary radiations reach the detector they can influence The shape of the recorded spectrum to noticeable extent .some possibilities are illustrated in (Fig.1.19) [2].

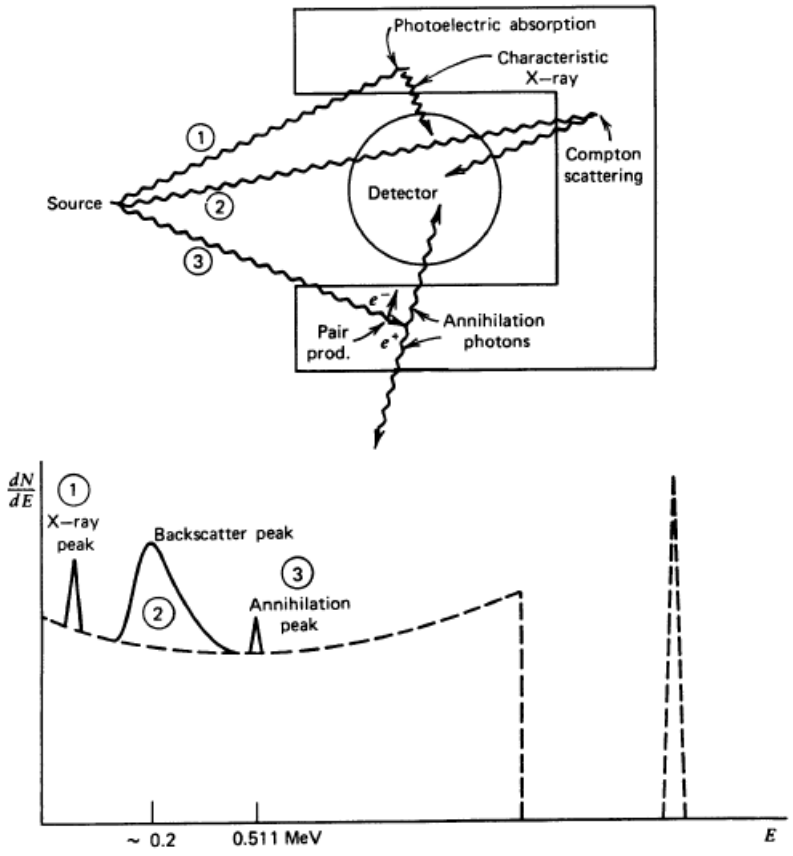

Figure 1.19: influence of surrounding materials on detector response. in addition to the expected spectrum, the representative histories shown at the top lead to the indicated corresponding features in the response function [9].

1.5.4.1. Backscattered gamma rays.

Pulse height spectra from gamma-ray detectors often show a peak in the vicinity of 0.2-0.25 MeV, called the backscatter peak. The peak is caused by gamma rays from the sources that have first interacted by Compton scattering in one of the materials surrounding the detector. (Fig.1.20) shows the energy dependence of these scattered gamma rays as a function of the scattering angle .From the shape of these curves, it can be seen that any scattering angle greater than about 110-120^{o} results in scattered photons of nearly identical energy. Therefore, a monoenergetic source will give rise to many scattered gamma rays whose energy is near this minimum value, and a peak will appear in the recorded spectrum [2].

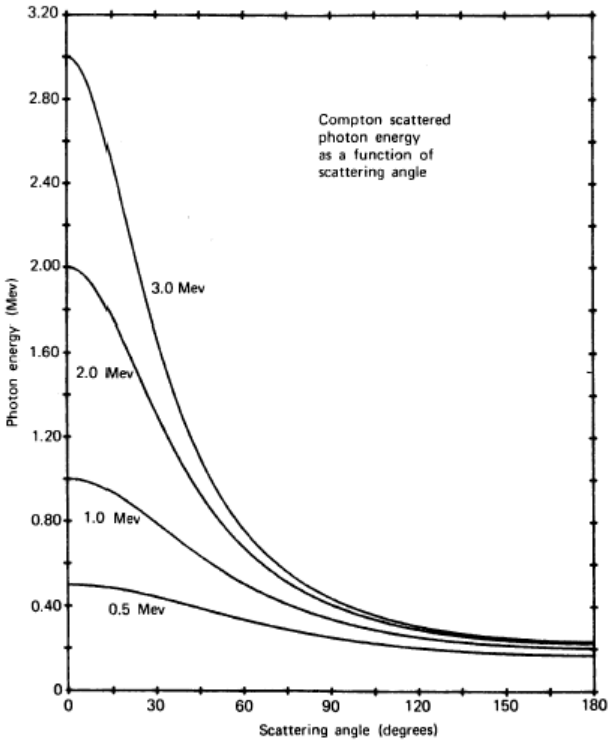

Figure 1.20: variation of scattered gamma ray energy with scattering angle [9].

1.5.4.2. Other secondary radiations.

In addition to Compton scattering, other interactions of the primary gamma rays in the surrounding materials can give noticeable peaks in the recorded spectrum. For example, photoelectric absorption in the materials immediately surrounding the detector can lead to generation of a characteristic X-ray that may reach the detector. If the energy of the primary gamma rays is high, pair within surrounding materials can give a significant yield of annihilation radiation. A peak can therefore appear at 0.511 MeV in the spectrum from the detection of these secondary photons [2].

1.6. Scintillation detectors.

1.6.1. Inorganic scintillators (Crystal scintillators).

Scintillation detectors contain a special materials-solid, liquid, gases (phosphor or fluor) that emits sparks or scintillations of light when

ionizing radiation transfers to it .when a charged particle (electron) transfers energy to matter, that energy either produces heat or raises other electrons into exited states .when the material is a scintillator, these excited states decay to lower energy stases, some of the excess energy being carried away by the emission of photons. To be useful, the wavelength of these photons must lie in the blue and /or long UV regions of the spectrum. Where the photomultiplier tube (PMT) is used to convert that light to electrons and amplify them for further processing and analysis; in all cases in which it is a charged particle that produces scintillation, the energy of electromagnetic radiation must first be transferred to electrons before any scintillation photons can be produced .the operation of scintillation detector may be divided into two broad [10].

Steps:

1- Absorption of incident radiation energy by the scintillator and production of photons in visible part of electromagnetic spectrum.
2- Amplification of the light by the photomultiplier tube and production of the output pulse.

The different types of scintillators are dividing into:

1- Inorganic scinillators.
2- Organic scintillators.
3- Gaseous scintillators.

Here we will discussion the first type (inorganic scintillators)

1.6.2. The mechanism of the scintillation process.

Energy absorption and photon emission by activated alkali-halide scintillators are complex processes most conveniently described by means of the band theory of solids. A pure single crystal is represented in (Fig.1.21), by a valence band, which is normally filled with electrons, and

the normally empty conduction band above it .separating them is a forbidden band of energies (~8 eV), called the band gap, where free electrons cannot exist. A particle interacting with the crystal may cause an electron to move from the valence band up the conduction band by an ionization process, producing a vacancy in the valance band that is called a hole. Conduction band electrons, and the valence band a holes, are free to move independently throughout the crystal. when a conduction band electron decays to the ground state, the emitted photon has a short wavelength (UV) with a high probability of being re-absorbed, and eventually contributing to the activator sites (below) .there is a finite probability that the quantity of energy that is deposited will be insufficient to produce ionization, but large enough to cause excitation, i.e., the elevation of an electronic state above the valance band. This electron will remain electrostatically bound to the hole it left in the valence band, to constitute an electron-hole pair called an exciton.

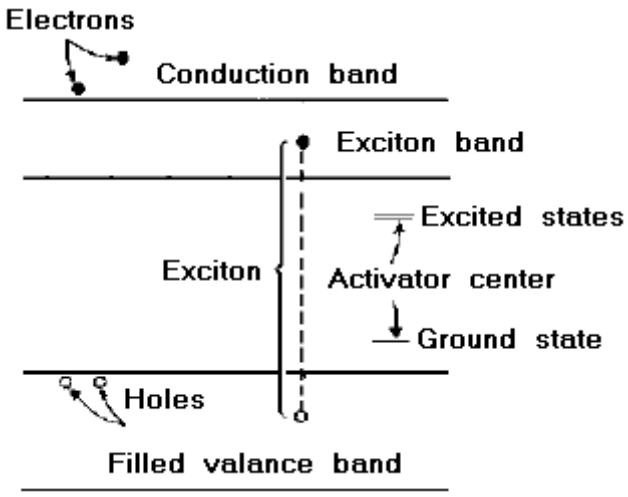

Figure 1.21: Schematic description the mechanism of scintillation process [10].

The exciton states from a thin band (width~1 eV) whose upper level will coincide with the lower edge of the conduction band. Lattice

imperfections such as vacancies or impurity atoms that are supplied by an "activator", produce relatively low energy states in the band gap at isolated sites in the crystal lattice. the elevation of an activator atom to an excited state may result from the absorption of photon produced by the decay of an excited state in the conduction band , the capture of a migrating electron and hole (in any order), or the capture of an exciton . The decay of an excited activator state produces photon in a decay time of the order of 100 ns, at a wavelength in the short blue or long UV region (visible region).When gamma ray interacts with scintillation material, visible light is given off. This visible light interacts with the photocathode, and electrons are emitted. These are the first two steps in the scintillation detection process. In the next step, the electrons are multiplied by 10^6 by the dynodes in the photomultiplier tube.

To illustrate the third step, let's follow one electron from the time it is emitted by the photocathode. The electron is attracted to the first positively charged dynode. When it strikes the dynode, more electrons (typically four) are emitted. The first dynode is shaped so that it directs the emitted electrons to the next dynode. The electrons are multiplied again by the second dynode and sent to the third dynode. The electron multiplicated continues throughout all the dynodes in the photomultiplier tube. The result is a large flow of electrons striking the anode. Typically, each electron emitted from the photocathode will end up as about a million electrons striking the anode.

In the fourth step the anode collects the electrons. A measurable electrical current is the result. The current is measured by the measuring device. The output of scintillation detectors a pulse of electrons that is proportional to the energy of the original radiation interacting with the scintillating

material .if the original radiation has more energy coming in ,there will be more light emitted more electrons, and a larger pulse.

Thus, production of scintillation is the result of the occurrence of these events:

1- Ionizing radiation passes through the crystal.
2- Electrons are raised to the conduction band.
3- Holes are created in the valance band.
4- Excitions are formed.
5- Activation centers are raised to the excited states by absorbing electrons , holes and excitons.
6- De-excitation if followed by the emission of photons.

most of the inorganic scintillators are crystal of alkali-halide metals as alkali iodides ,which contain a small concentration of an impurity example NaI(Tl),CsI(Tl),CaI(Na),LiI(Eu),andCaf_2(Eu). The element in parentheses is the impurity or activator. The most common alkali-halide scintillators are sodium iodide [NaI(Tl)] with about (0.1% by mass) thallium activator content [10,11].

1.6.3. The NaI(Tl) scintillation detector.

Different types of scintillating material are used to detect different types of radiation. For example, a thin layer of zinc sulfide is generally used to detect alpha radiation; an anthracene crystal is used for beta; and a sodium iodide thallium activated crystal detects gamma. Sodium iodide is the crystal most often used in the scintillation detectors used in nuclear medicine. A schematic of a typical thallium-activated sodium iodide crystal and photomultiplier tube is shown in (Fig.1.22).a thallium-activated sodium iodide crystal is formed by adding trace amounts of thallium to a pure sodium iodide crystal during growth. Sodium iodide

crystals are hygroscopic and must be sealed in an air-tight enclosure to avoid absorption of moisture from exposure to air.

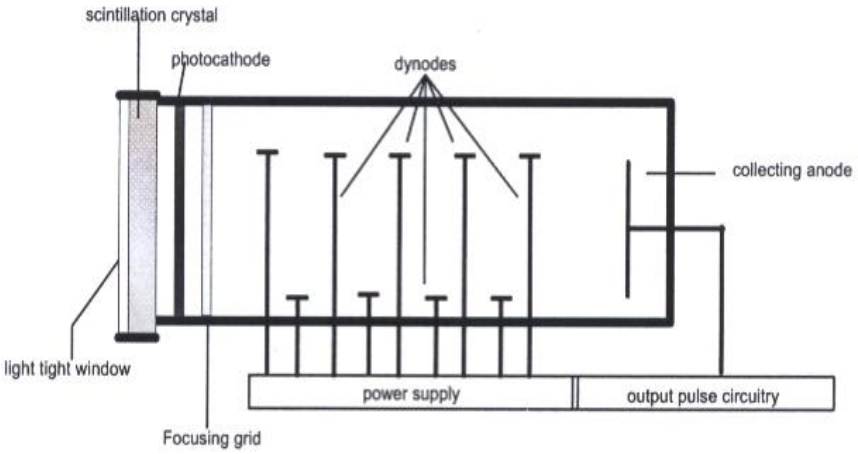

Figure 1.22: NaI(Tl) scintillation detector [12].

crystals that have been exposed to air for any length of time lose the properties of transparency and light transmission and are said to be "yellowed" the crystal is covered with a highly reflective coating so that light photons emitted in directions other than toward the exit window are eventually reflected out the window to the photomultiplier, the device that converts the light photons into an electric signal. The exit window of the crystal is constructed of highly polished glass, which is coupled to the photomultiplier with optical gel or epoxy. This optical coupling is required to match the indexes of refraction of the exit window of the crystal to the entrance window of the photomultiplier to maximize light transmission and minimize light refraction or spreading [10,13].

(Fig.1.23) shown the emission spectrum of NaI(Tl).the emission maximum is well matched to sensitivity curve of photomultiplier tube with bialkali photocathode.

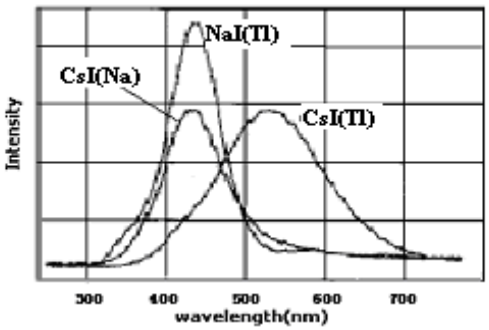

Figure 1.23: Scintillation emission spectrum of NaI(Tl) and other scintillation materials [14].

NaI(Tl) Produces the highest signal in a (PMT) per amount of radiation absorbed in crystal of all presently known scintillators.under optimum conditions, an average of $1*10^4$ photoelectrons are produced per MeV γ-rays [14].

The relation between the scintillation intensity and the temperature is shown in (Fig.1.24) for several alkali halide scintillators. The shape of the curves for CsI(Tl) and CsI(Na) are so close that they are represented by the same curve.

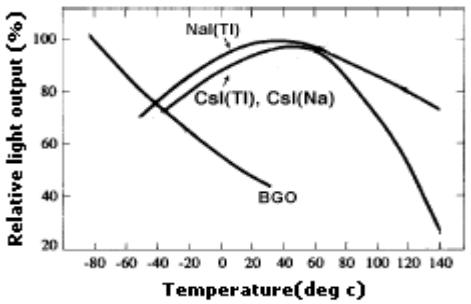

Figure 1.24: Temperature response of various scintillation materials [14].

NaI(Tl) exhibits several decay time constants. The primary single exponential decay constant is 0.25 μs at room temperature [14]. The relation between the effective decay time and the temperature is presented in (Fig.1.25) [14].

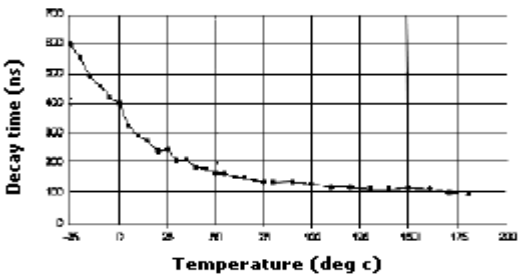

Figure 1.25: Temperature dependence of the decay time of NaI(Tl) [14].